

# Particulate Air Pollution and Daily Mortality on Utah's Wasatch Front

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Reviews of daily time-series mortality studies from many cities throughout the world suggest that daily mortality counts are associated with short-term changes in particulate matter (PM) air pollution. One U.S. city, however, with conspicuously weak PM-mortality associations was Salt Lake City, Utah; however, relatively robust PM-mortality associations have been observed in a neighboring metropolitan area (Provo/Orem, Utah). The present study explored this apparent discrepancy by collecting, comparing, and analyzing mortality, pollution, and weather data for all three metropolitan areas on Utah's Wasatch Front region of the Wasatch Mountain Range (Ogden, Salt Lake City, and Provo/Orem) for approximately 10 years (1985–1995). Generalized additive Poisson regression models were used to estimate PM-mortality associations while controlling for seasonality, temperature, humidity, and barometric pressure. Salt Lake City experienced substantially more episodes of high PM that were dominated by windblown dust. When the data were screened to exclude obvious windblown dust episodes and when PM data from multiple monitors were used to construct an estimate of mean exposure for the area, comparable PM-mortality effects were estimated. After screening and by using constructed mean  $PM \leq 10 \mu m$  in aerodynamic diameter ( $PM_{10}$ ) data, the estimated percent change in mortality associated with a  $10\text{-mg}/m^3$  increase in  $PM_{10}$  (and 95% confidence intervals) for the three Wasatch Front metropolitan areas equaled approximately 1.6% (0.3–2.9), 0.8% (0.3–1.3), and 1.0% (0.2–1.8) for the Ogden, Salt Lake City, and Provo/Orem areas, respectively. We conclude that stagnant air pollution episodes with higher concentrations of primary and secondary combustion-source particles were more associated with elevated mortality than windblown dust episodes with relatively higher concentrations of coarse crustal-derived particles. **Key words:** air pollution, barometric pressure, combustion particles, mortality, particulate pollution, windblown dust. *Environ Health Perspect* 107:567–573 (1999). [Online 4 June 1999]  
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Numerous daily time-series studies have reported changes in daily death counts associated with short-term changes in particulate matter (PM) air pollution. Reviews of these studies indicate that they generally observed positive and often statistically significant associations between daily mortality counts and PM air pollution even after controlling for seasonality and various weather variables (1–9). Because different measurements of PM pollution and modeling strategies were used, precise comparisons of PM effect estimates across the studies are difficult. However, effect estimates of an approximately 0.5–1.5% increase in total mortality counts associated with a  $10\text{-}\mu g/m^3$  increase in  $PM \leq 10 \mu m$  in aerodynamic diameter ( $PM_{10}$ ) were typical. Effect estimates were larger when deaths due to cardiopulmonary disease were evaluated.

A recent review of the epidemiologic studies of PM notes reasonably consistent effect estimates of PM on daily mortality across studies from more than 30 cities throughout the world (9). There were somewhat smaller effect estimates from several Eastern European cities. The U.S. city with the lowest effect estimate was Salt Lake City, Utah. Two recent studies of daily mortality counts from this city reported no positive association between mortality and PM

(10,11). These Salt Lake City findings are conspicuous because several analyses have observed positive associations between PM and mortality in the neighboring metropolitan area of Provo/Orem, Utah (11–14). Boucher and colleagues (11) speculate that the lack of association between mortality and PM in Salt Lake City may be due to inadequate exposure measurements or differences in the particulate composition. Gamble and Lewis (15) interpret these results as support that associations between PM and mortality are not causal but likely are related to an uncontrolled confounder.

The primary objective of this paper is to evaluate the consistency or lack of consistency of apparent PM effects on mortality in Utah's Wasatch Front metropolitan areas. The impact of episodes of high windblown dust concentrations and the adequacy of using a single central site pollution monitor versus a constructed mean of PM data from several sites will be explored. A secondary objective of this paper is to evaluate potential associations between barometric pressure and mortality and to explore the sensitivity of the estimated pollution effects to controlling for barometric pressure. Expanded mortality and pollution data for all three metropolitan areas of Utah's Wasatch Front, including Salt Lake City,

will be collected and potential relationships between PM air pollution and mortality will be evaluated across the entire area using similar time periods and methodology.

## Methods

**Study area.** Approximately 80% of Utah's population resides on a relatively narrow strip of land that fronts the Wasatch mountain range. This land area, commonly called the Wasatch Front, is approximately 15–25 km wide from east to west and approximately 130 km long from north to south. It is bordered on the east by the Wasatch Mountains and on the west largely by the Great Salt Lake, Utah Lake, and smaller mountain ranges. There are three metropolitan areas on the Wasatch Front: a) the city of Ogden and surrounding communities to the north; b) Salt Lake City and surrounding communities located in the center; and c) Provo/Orem and surrounding communities to the south. Although the entire Wasatch Front shares common weather patterns, emission sources of pollution differ across the three metropolitan areas, resulting in somewhat different pollution levels and patterns. All three Wasatch Front metropolitan areas were used in this analysis. The Ogden area was defined to include Weber County, with a 1992 population equal to approximately 165,000 persons. The Salt Lake City area included Salt Lake and Davis Counties, with a 1992 population equal to approximately 965,000 persons. The Provo/Orem area included Utah County, with a 1992 population equal to approximately 275,000 persons.

**Mortality and weather data.** Mortality data files for 1985–1995 were obtained from the Utah State Department of Health, Bureau of Vital Records and Health Statistics (Salt Lake City, UT). Nondisease deaths [International Classification of Diseases, 9th Revision (ICD-9) codes > 800 World Health Organization, Geneva], deaths of persons who resided outside of the Wasatch Front or who died outside of the Wasatch Front, and deaths that occurred outside the person's metropolitan area of residence were excluded. Mortality was divided across the

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three metropolitan areas based on the country of residence at the time of death. In the Ogden, Salt Lake, and Provo/Orem areas no  $PM_{10}$  data were available prior to 10 January 1986, 2 June 1985, and 7 April 1985, respectively. For each of these areas, all deaths prior to these dates were excluded. Mortality was also divided into three broad cause-of-death categories including respiratory disease deaths (*ICD-9* codes 480–486 and 490–496); cardiovascular disease deaths (*ICD-9* codes 390–448); and all other deaths, excluding *ICD-9* codes > 800.

Daily climatological data, including daily minimum temperature, dew point, barometric pressure, and the clearing index were collected from the National Weather Service (Salt Lake City International Airport station). The National Weather Service computes a clearing or air stagnation index for the Wasatch Front as a profile of the atmosphere which incorporates temperature, moisture, and winds into an index that measures the vertical and horizontal motion of particles in the air (16). The index ranges from 0 to 1,000. Low index values reflect stagnant air conditions with little windblown dust but a build up of primary and secondary combustion-source particulate pollution in addition to other pollutants from vehicles, industry, wood-burning, and other sources. High index values reflect more wind, which blows these local combustion-source pollutants out of the valleys but that also results in more localized windblown dust.

**Particulate air pollution data.** Respirable particulate air pollution data were obtained from the Utah Department of Environmental Quality, Division of Air Quality (Salt Lake City, UT).  $PM_{10}$  monitoring was conducted in accordance with the U.S. Environmental Protection Agency method (17). In the Ogden area there was only one  $PM_{10}$  monitor that collected daily data. It was centrally located in Ogden and was used in this analysis for the Ogden metropolitan area. Daily monitoring was conducted at three sites in the Provo/Orem metropolitan area, including the Lindon, West Orem, and North Provo sites. The Lindon monitoring site was used because it was the first  $PM_{10}$  site to be established, it had the most available data, and because the  $PM_{10}$  concentrations at the other two sites closely correlated with concentrations at the Lindon site ( $r > 0.90$ ). However, in this analysis, in addition to using the Lindon monitor, data from all three monitors were used to create daily constructed mean  $PM_{10}$  values for the area. Missing  $PM_{10}$  data were imputed by first estimating linear regression models by regressing daily  $PM_{10}$  values from each monitor on values from each of

the other two monitors. Missing data for each monitor were estimated based on the regression models and air pollution levels for the most closely correlated monitor without missing  $PM_{10}$  data. The constructed mean was then calculated by averaging monitored or estimated  $PM_{10}$  values from the three monitors. If  $PM_{10}$  data were missing for all three monitors, the constructed mean value was also treated as missing.

The Salt Lake City area is the largest area both in terms of population and geography. Data from several  $PM_{10}$  monitors in the area were available and were used in the analysis including *a*) the Air Monitoring Center/Health Department (AMC/HD) monitor, the most centrally located monitor near the Salt Lake City center; *b*) the North Salt Lake Monitor, located in the northern part of the metropolitan area; *c*) the Magna monitor, located in the western part of the area; and *d*) the Cottonwood monitor, located toward the southeast part of the area. In this analysis the centrally located AMC/HD monitor was used in addition to a constructed mean for the area using data from all four of the Salt Lake City monitors. As for the Provo/Orem area, missing  $PM_{10}$  data were imputed by first estimating linear regression models by regressing daily  $PM_{10}$  values from each monitor on values from each of the other monitors. Then, missing data for each monitor were estimated based on the regression models and air pollution levels for the most closely correlated monitor without missing  $PM_{10}$  data. The constructed mean was then calculated by averaging either monitored or estimated  $PM_{10}$  values from the four monitors. If the  $PM_{10}$  data were missing for all four monitors, the constructed mean value was also treated as missing.

In all three Wasatch Front metropolitan areas, low-level temperature inversion episodes are common during winter months. During these episodes, concentrations of particulate air pollution can become highly elevated because of trapped local emissions in the stagnant air mass near the valley floors and because of the rapid conversion of  $SO_2$  and  $NO_2$  to sulfates and nitrates. The Utah Department of Environmental Quality, Division of Air Quality, conducted limited monitoring of  $PM_{10}$ ,  $PM_{2.5}$ , and  $PM_1$  in the winter of 1995–1996 in Salt Lake City. During temperature-inversion-related stagnant air pollution episodes, approximately 70–90% of the  $PM_{10}$  mass was made up of particles < 2.5  $\mu m$  in diameter and approximately 55–70% of the  $PM_{10}$  mass was made up of particles < 1  $\mu m$  in diameter. These data clearly suggest that during stagnant air mass conditions, elevated particulate pollution is due primarily to the

buildup of primary and secondary fine combustion-source particles (18).

Elevated levels of  $PM_{10}$  can also occur on days without stagnant air conditions—on days with a high clearing index, which indicates higher winds, more windblown dust, and higher concentrations of more coarse, crustal-derived particles. Therefore, for this analysis screened and unscreened  $PM_{10}$  data were used. The pollution data were screened to exclude pollution episodes dominated by high levels of windblown dust. This was defined in two ways. Screen I excluded days when the  $PM_{10}$  levels exceeded 50  $\mu g/m^3$  and the clearing index was > 800. Screen II was based on a visual evaluation of 5-day lagged moving average  $PM_{10}$  levels plotted over 5-day lagged moving averages of the clearing index. Based on this evaluation, Screen II excluded days with a 5-day moving average clearing index > 400 and a 5-day lagged moving average  $PM_{10}$  > 50, 62.5, and 75 for the Ogden, Salt Lake City, and Provo/Orem metropolitan areas, respectively.

**Statistical analysis.** Mortality is classically modeled as following a Poisson process, which generates independent and random occurrences across time or space (19,20). In this analysis deaths were sorted into discrete 24-hr periods of time (days), generating daily death counts that should theoretically be Poisson distributed. Poissonian variation will likely account for most of the day-to-day variation in death counts, although the underlying mean of the Poisson process may be nonstationary and determined by pollution levels, season, weather, or other factors. In this study Poisson regression analysis was used to try to model the temporal relationships between daily mean mortality counts and daily changes in pollution while controlling for seasonality, time trends, and weather variables and recognizing that the majority of the day-to-day variability is Poissonian.

For each of the three Wasatch Front metropolitan areas, a series of nonparametric or generalized additive Poisson regression models (21) were estimated. To account for time trends and seasonality and potential nonlinear effects of temperature and humidity, the models were fit using cubic smoothing splines for time, daily minimum temperature, and daily dew point. In the base models, the smooths of time used 4 degrees of freedom (*df*) per year (a total of 40, 42, and 44 *df* for the Ogden, Salt Lake, and Provo/Orem metropolitan areas, respectively). Also, 4 *df* were used for the smooths of daily minimum temperature and dew point. An analysis of the autocorrelation of the residuals was conducted and additional models were also estimated that selected degrees of freedom based on the Akaike



information criterion (AIC) (21). Initial analysis indicated a near linear association with barometric pressure, so it was also included as a linear variable. Base models included  $PM_{10}$  variables as linear variables; however, to further explore the concentration–response relationship between  $PM_{10}$  and mortality, models were also fit using regression smoothing (cubic smoothing splines) of  $PM_{10}$ .

Models were estimated for total mortality and mortality divided into broad cause-of-death categories. Models were estimated using  $PM_{10}$  data from a monitor from a single site as well as the constructed mean  $PM_{10}$  data. These models were also estimated using unscreened  $PM_{10}$  data and  $PM_{10}$  data screened to exclude pollution episodes dominated by high levels of wind-blown dust using both screen I and screen II. Models were estimated with and without controlling for barometric pressure. Based on previously reported studies (10–14), the lag structure for particulate pollution used in most of the models was a 5-day lagged moving average of  $PM_{10}$  (the mean of the nonmissing values of  $PM_{10}$  for the concurrent day and the previous 4 days). Other lag structures were also explored, including concurrent-day  $PM_{10}$  and 3- and 7-day lagged moving averages. All the regression models in this analysis were estimated using the generalized additive model (GAM function) and the smoothing spline smoothers (s function) of S-PLUS statistical software (22).

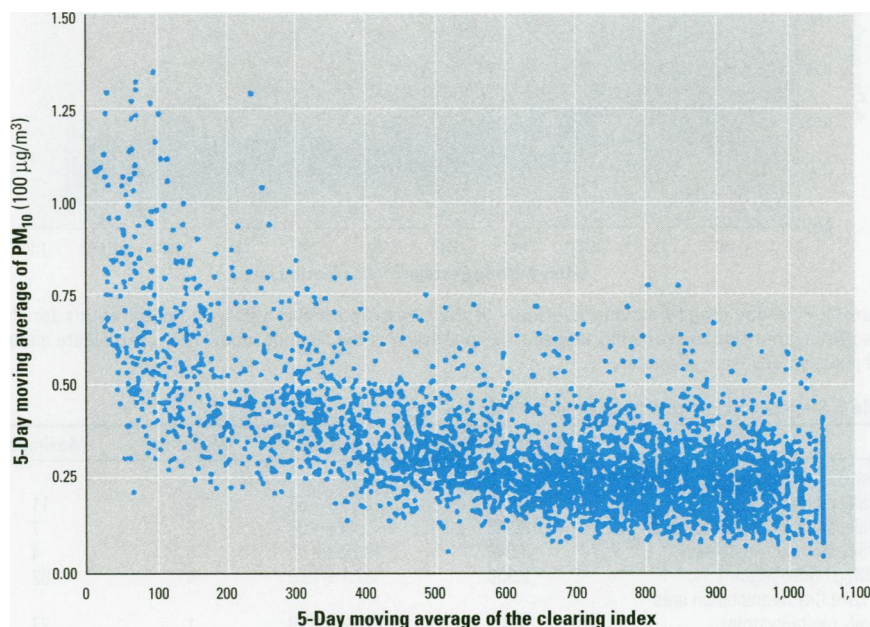
## Results

**$PM_{10}$  levels and clearing index.** Figures 1–3 present the 5-day lagged moving average of  $PM_{10}$  plotted over 5-day lagged moving averages of the clearing index. These figures show that low clearing index values are often, but not always, associated with relatively high  $PM_{10}$  levels. These low clearing index values reflect stagnant air conditions and higher concentrations of primary and secondary combustion-source particulate pollution in addition to other pollutants from vehicles, industry, wood-burning, and other sources. These figures also show that relatively high clearing index values are usually associated with relatively low  $PM_{10}$  levels because higher clearing index values reflect more clearing of local combustion-source pollutants out of the valleys. Figures 1–3 indicate that elevated levels of  $PM_{10}$  sometimes occurred on days that did not have stagnant air conditions. Instead they occurred on days with a high clearing index, which indicated higher winds, more wind-blown dust, and higher concentrations of more coarse, crustal-derived particles. Such occurrences were rare in the Provo/Orem

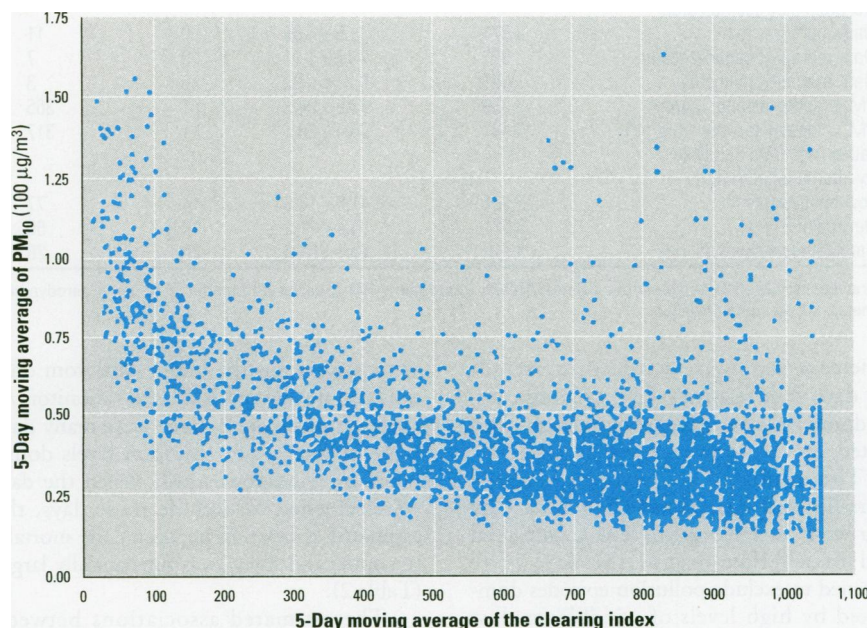
area but were relatively common in the Salt Lake City area, probably due to the existence of tailings piles of a large copper mine, gravel pits, cement plants, salt flats, open fields, etc.

**$PM_{10}$ –mortality associations.** The mortality, pollution, and weather variables used in the analysis are summarized in Table 1. Table 2 summarizes the basic regression results. After controlling for long-term time trend, seasonality, barometric pressure, and

weather variables, daily mortality counts were positively associated with 5-day lagged moving average concentrations of  $PM_{10}$  in all three Wasatch Front metropolitan areas. The estimated association between mortality and  $PM_{10}$  was largest in the Ogden area; however, because the Ogden area also had the smallest population, the smallest mean death counts, and the smallest number of days of available data, the standard errors of the estimates were also relatively large.

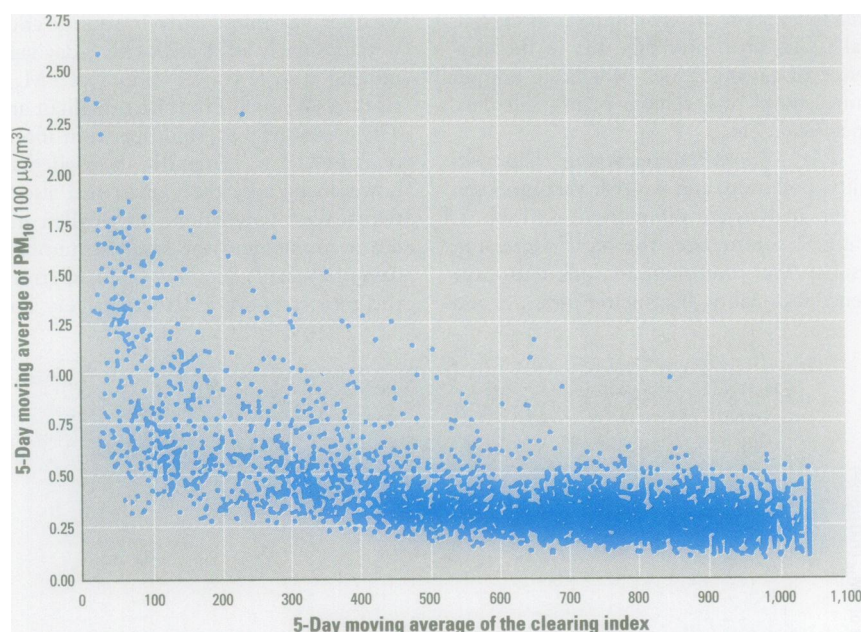


**Figure 1.** Five-day lagged moving average  $PM_{10}$  concentrations from the Ogden monitor plotted over 5-day lagged moving average of the clearing index.  $PM_{10}$ , particulate matter  $\leq 10 \mu m$  in aerodynamic diameter.



**Figure 2.** Five-day lagged moving averages of the constructed mean  $PM_{10}$  concentrations for the Salt Lake City area plotted over 5-day lagged moving average of the clearing index.  $PM_{10}$ , particulate matter  $\leq 10 \mu m$  in aerodynamic diameter.





**Figure 3.** Five-day lagged moving averages of the constructed mean  $PM_{10}$  concentrations for the Provo/Orem area plotted over 5-day lagged moving average of the clearing index.  $PM_{10}$ , particulate matter  $\leq 10 \mu m$  in aerodynamic diameter.

**Table 1.** Summary of key variables in the analysis.

	Observed (no.)	Mean $\pm$ SD	Minimum	Maximum
Ogden metropolitan area				
Daily mortality, total	3,643	$2.55 \pm 1.65$	0	11
Daily mortality, cardiovascular	3,643	$1.14 \pm 1.08$	0	7
Daily mortality, pulmonary	3,643	$0.26 \pm 0.51$	0	4
$PM_{10}$ , Ogden ( $\mu g/m^3$ )	2,308	$32.1 \pm 19.9$	4	182
Salt Lake City metropolitan area				
Daily mortality, total	3,865	$11.32 \pm 3.59$	1	27
Daily mortality, cardiovascular	3,865	$4.72 \pm 2.21$	0	14
Daily mortality, pulmonary	3,865	$0.96 \pm 1.00$	0	7
$PM_{10}$ , AMC/HD monitor ( $\mu g/m^3$ )	2,717	$41.6 \pm 28.0$	3	228
$PM_{10}$ , constructed mean ( $\mu g/m^3$ )	3,700	$41.2 \pm 26.8$	7	441
Provo/Orem metropolitan area				
Daily mortality, total	3,921	$2.65 \pm 1.69$	0	11
Daily mortality, cardiovascular	3,921	$1.17 \pm 1.11$	0	7
Daily mortality, pulmonary	3,921	$0.27 \pm 0.52$	0	3
$PM_{10}$ , Lindon monitor ( $\mu g/m^3$ )	3,339	$42.5 \pm 34.2$	1	365
$PM_{10}$ , constructed mean ( $\mu g/m^3$ )	3,687	$38.4 \pm 29.1$	1	317
Weather data from Salt Lake				
City International Airport				
Low temperature ( $^{\circ}F$ )	3,921	$41.8 \pm 16.6$	-14	77
Dew point ( $^{\circ}F$ )	3,921	$34.4 \pm 11.0$	-10	66
Barometric pressure (in. Hg)	3,919	$25.7 \pm 0.16$	25	26.3

Abbreviations: AMC/HD, Air Monitoring Center/Health Department;  $PM_{10}$ , particulate matter  $\geq 10 \mu m$  in aerodynamic diameter; SD, standard deviation.

When the data were screened to exclude the days with relatively high pollution levels dominated by windblown dust, the estimated association was somewhat larger.

The estimated associations between mortality and  $PM_{10}$  in the Salt Lake City area were sensitive to the  $PM_{10}$  data used and to whether or not the data were screened to exclude pollution episodes dominated by high levels of windblown dust (Table 2). The estimated pollution effect was substantially larger when daily constructed mean values of all four monitors

were used versus the use of data from only the centrally located AMC/HD monitor. As observed in Figure 2, there were many days with relatively high pollution levels dominated by windblown dust. When the data were screened to exclude these days, the estimated association between daily mortality counts and  $PM_{10}$  was substantially larger (Table 2).

The estimated associations between daily mortality and particulate pollution in the Provo/Orem area were positive and generally not very sensitive to the use of data

from the single centrally located monitor versus a constructed mean from data from three monitors or from screening the data to exclude days with pollution dominated by high levels of windblown dust. Figure 3 shows that there were only a few days with moderately high  $PM_{10}$  levels dominated by windblown dust. Screening the data to exclude these days did little to change the estimated association between daily mortality counts and  $PM_{10}$ .

**Sensitivity of results to modeling.** An analysis of the autocorrelation of the model residuals for all three areas indicated no clear pattern of significant autocorrelation. Nevertheless, additional models were also estimated using AIC to select the degrees of freedom used in the nonparametric smooths of time, temperature, and dew point (results not presented). Using AIC generally resulted in using fewer degrees of freedom for temperature and dew point. The degrees of freedom used for time generally remained approximately the same in Ogden, increased in Salt Lake City, and decreased in Provo/Orem. The estimated associations between  $PM_{10}$  and mortality, however, were not substantially effected.

The estimated associations between  $PM_{10}$  and mortality were substantially affected by the choice of lag structure used for  $PM_{10}$ . Table 3 presents regression coefficients and standard errors for models that used different lag structures for  $PM_{10}$ , including concurrent-day and 3-, 5-, and 7-day lagged moving averages. It was unclear which was generally the best-fitting lag. Interestingly, when a 7-day lagged moving average was used, the effect estimates were nearly identical for all three areas.

Table 4 summarizes the sensitivity of the estimated  $PM$ -mortality association across alternative model specifications. Positive, statistically significant ( $p < 0.05$ ) associations between daily mortality and  $PM_{10}$  were observed for all model specifications. A comparison of models 1 and 2, however, demonstrates that adding a nonparametric smooth of time (cubic smoothing spline, 4 *dof*/year to control for long-term time trends and seasonality reduces the estimated  $PM_{10}$  effect. Additional inclusion of the weather variables, barometric pressure, daily low temperature, and dew point resulted in somewhat larger  $PM_{10}$  effect estimates (compare models 3, 4, and 5 with model 2).

**Seasonal, barometric pressure, and weather effects.** The analysis of daily mortality counts across all three Wasatch Front areas observed rather consistent effects of season and barometric pressure. Figure 4 presents the daily mortality counts in Salt Lake City plotted over time along with a

cubic smoothing spline with 42 *df*. It is clear in this plot that underlying the Poissonian variability there is seasonality in the mortality counts. The difference in mortality counts during the wintertime peak mortality periods versus the summertime low periods is typically approximately two deaths per day. Similar seasonality patterns were also observed in the Ogden and Provo/Orem areas, although the counts were smaller because of the areas' smaller populations. After controlling for seasonality, mortality associations with temperature and dew point were relatively weak. In all three metropolitan areas temperature was negatively associated with mortality counts. No consistent pattern of association between mortality and dew point was observed. Excepting seasonality, the most robust weather-related effect was with barometric pressure. The Poisson regression coefficients (and standard errors) for mortality and barometric pressure are presented in Table 5. For all three areas, barometric pressure was negatively associated with mortality, especially total and cardiovascular mortality.

***PM<sub>10</sub>-mortality concentration-response relationships.*** To further explore the PM<sub>10</sub>-mortality concentration-response relationships, models were also fit using regression smoothing (cubic smoothing splines, *df* = 4) of PM<sub>10</sub>. These models used the Ogden monitor for the Ogden area and the constructed mean for the Salt Lake City and Provo/Orem areas and they used the screened PM<sub>10</sub> (screen I) data for all three areas. As in the Table 2 model estimates, these models also included barometric pressure and cubic smoothing splines for time, daily low temperature, and daily dew point. The estimated concentration-response relationships from these models for the Ogden, Salt Lake City, and Provo/Orem areas were similar to those estimated in the models that included PM<sub>10</sub> as a linear term in the model. For all three associations, a statistically significant (*p* < 0.05) positive linear association between PM<sub>10</sub> and mortality was observed. Partial tests for the contribution of the smooths in the model versus just a linear term for PM<sub>10</sub> indicated that these PM<sub>10</sub>-mortality response relationships were not significantly different from linear (*p* = 0.54, 0.31, and 0.72 for the Ogden, Salt Lake City, and Provo/Orem areas, respectively).

## Discussion

The primary objective of this analysis was to evaluate the consistency or lack of consistency of apparent particulate air pollution effects on mortality along Utah's Wasatch Front. Similar to previous analyses of Salt Lake City area mortality data (10,11), this analysis observes relatively weak associations

**Table 2.** Poisson regression coefficients (× 100) (and standard errors) for 5-day lagged PM<sub>10</sub>.<sup>a</sup>

	PM <sub>10</sub>		
	Unscreened	Screen I	Screen II
Ogden			
Total mortality	0.157 (0.065)	0.162 (0.066)	0.182 (0.067)
Cardiovascular mortality	0.039 (0.098)	0.023 (0.100)	0.028 (0.103)
Pulmonary mortality	0.318 (0.186)	0.355 (0.188)	0.427 (0.190)
Salt Lake City (AMC/HD monitor PM <sub>10</sub> )			
Total mortality	0.037 (0.024)	0.041 (0.024)	0.037 (0.024)
Cardiovascular mortality	0.076 (0.036)	0.081 (0.036)	0.065 (0.037)
Pulmonary mortality	-0.013 (0.078)	-0.003 (0.078)	0.028 (0.080)
Salt Lake City (constructed mean PM <sub>10</sub> )			
Total mortality	0.050 (0.025)	0.077 (0.026)	0.087 (0.027)
Cardiovascular mortality	0.080 (0.037)	0.124 (0.040)	0.126 (0.042)
Pulmonary mortality	0.079 (0.084)	0.147 (0.087)	0.157 (0.090)
Provo/Orem (Lindon monitor PM <sub>10</sub> )			
Total mortality	0.097 (0.036)	0.087 (0.036)	0.097 (0.036)
Cardiovascular mortality	0.137 (0.052)	0.127 (0.052)	0.140 (0.052)
Pulmonary mortality	0.108 (0.107)	0.083 (0.108)	0.090 (0.110)
Provo/Orem (constructed mean PM <sub>10</sub> )			
Total mortality	0.110 (0.041)	0.095 (0.041)	0.108 (0.042)
Cardiovascular mortality	0.166 (0.060)	0.147 (0.060)	0.165 (0.060)
Pulmonary mortality	0.054 (0.126)	0.050 (0.126)	0.044 (0.128)

Abbreviations: AMC/HD, Air Monitoring Center/Health Department; *df*, degrees of freedom; PM<sub>10</sub>, particulate matter ≤ 10 μm in aerodynamic diameter.

<sup>a</sup>Models are fit with PM<sub>10</sub> and barometric pressure included as linear variables but using cubic smoothing splines for time (40, 42, and 44 *df* for Ogden, Salt Lake, and Provo/Orem, respectively), daily low temperature (4 *df*), and daily dew point (4 *df*).

**Table 3.** Poisson regression coefficients (× 100) (and standard errors) for alternative lag structures for PM<sub>10</sub>.<sup>a</sup>

	Concurrent day	3-Day lagged moving average	5-Day lagged moving average	7-Day lagged moving average
Ogden total mortality	0.227 (0.071)	0.136 (0.062)	0.162 (0.065)	0.100 (0.070)
Salt Lake City total mortality	0.046 (0.023)	0.056 (0.024)	0.077 (0.026)	0.092 (0.028)
Provo/Orem total mortality	0.037 (0.041)	0.084 (0.040)	0.095 (0.041)	0.096 (0.043)

Abbreviations: *df*, degrees of freedom; PM<sub>10</sub>, particulate matter ≤ 10 μm in aerodynamic diameter.

<sup>a</sup>Models are fit with PM<sub>10</sub> (screen I, Ogden monitor for the Ogden area and the constructed mean for the Salt Lake City and Provo/Orem areas) and barometric pressure included as linear variables but using cubic smoothing splines for time (40, 42, and 44 *df* for Ogden, Salt Lake, and Provo/Orem, respectively), daily low temperature (4 *df*), and daily dew point (4 *df*).

**Table 4.** Poisson regression coefficients (× 100) (and standard errors) for PM<sub>10</sub> across alternative model specifications.<sup>a</sup>

Model	Variables included in models	Ogden	Salt Lake City	Provo/Orem
1	5-Day lagged moving average of PM <sub>10</sub>	0.184 (0.061)	0.093 (0.024)	0.094 (0.036)
2	Model 1 + cubic smoothing splines of time ( <i>df</i> = 4/year)	0.130 (0.062)	0.052 (0.025)	0.075 (0.037)
3	Model 2 + cubic smoothing splines of temperature and a dew point ( <i>df</i> = 4)	0.142 (0.065)	0.061 (0.026)	0.080 (0.040)
4	Model 2 + barometric pressure	0.143 (0.064)	0.067 (0.026)	0.089 (0.039)
5	Model 3 + barometric pressure	0.162 (0.066)	0.077 (0.026)	0.095 (0.041)

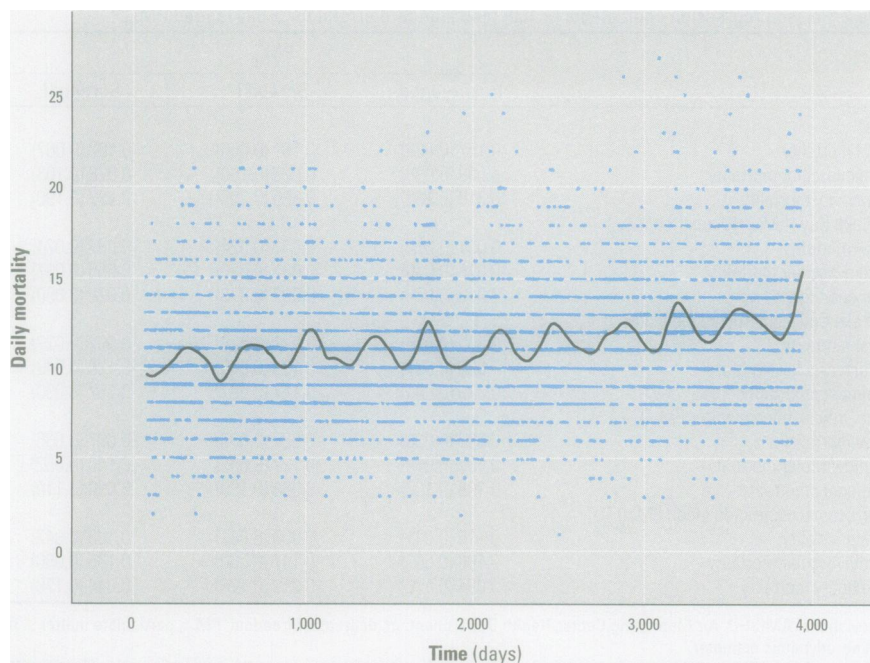
Abbreviations: *df*, degrees of freedom; PM<sub>10</sub>, particulate matter ≤ 10 μm in aerodynamic diameter.

<sup>a</sup>Models are fit with PM<sub>10</sub> (screen I, Ogden monitor for the Ogden area and the constructed mean for the Salt Lake City and Provo/Orem areas).

between PM<sub>10</sub> and mortality as compared to neighboring Wasatch Front communities or other U.S. cities. There is speculation that this is due to inadequate exposure measurements or that it is due to differences in the particulate composition (11). The present analysis supports both of these speculations. In this analysis, the estimated association between PM<sub>10</sub> and mortality was larger when mean data from multiple monitors were used. Furthermore, the most obvious difference between the Salt Lake City area and the Provo/Orem area was the relatively large contribution of windblown dust

episodes in the Salt Lake City area. The estimated association between PM<sub>10</sub> and mortality was strengthened when the data were screened to exclude episode days that were obviously dominated by windblown dust. These results suggest that the pollution episodes of windblown dust with higher concentrations of crustal-derived particles were less associated with elevated mortality than were episodes of particulate pollution due primarily to the buildup of primary and secondary fine combustion-source particles common during stagnant air mass conditions.





**Figure 4.** Daily mortality counts in the Salt Lake City metropolitan area plotted versus time and the cubic smoothing spline.

**Table 5.** Poisson regression coefficients (and standard errors) for barometric pressure (1 inch Hg) across the study areas and cause of death.<sup>a</sup>

	Ogden	Salt Lake City	Provo/Orem
Total mortality	-0.152 (0.069)	-0.111 (0.031)	-0.102 (0.064)
Cardiovascular mortality	-0.218 (0.103)	-0.123 (0.048)	-0.139 (0.096)
Pulmonary mortality	-0.007 (0.209)	-0.052 (0.105)	-0.031 (0.199)

Abbreviations: *df*, degrees of freedom; PM<sub>10</sub>, particulate matter  $\leq 10 \mu\text{m}$  in aerodynamic diameter.

<sup>a</sup>Other variables included in the models were 5-day lagged moving average PM<sub>10</sub> (screen 1, Ogden monitor for the Ogden area and the constructed mean for the Salt Lake City and Provo/Orem areas) and cubic smoothing splines for time (40, 42, and 44 *df* for Ogden, Salt Lake, and Provo/Orem, respectively), daily low temperature (4 *df*), and daily dew point (4 *df*).

Because the Salt Lake City area is large and is home to a highly mobile population, a daily constructed mean particulate pollution measure using multiple monitors may provide a better estimate of average daily changes in exposures than data from a single central site. Unfortunately, even the constructed mean is based on limited data and may represent less than adequate estimates of exposure. Furthermore, episodes of high particulate air pollution were more often due to windblown dust in the Salt Lake City area than in the neighboring communities. This analysis used concentration levels and the clearing index to attempt to distinguish pollution episodes dominated by high levels of windblown dust. Such an approach is somewhat crude and is inferior to direct daily measurements of the fine fraction of PM<sub>10</sub> or other constituents of PM<sub>10</sub>.

The estimated percent change in mortality associated with a 10- $\mu\text{g}/\text{m}^3$  increase in PM<sub>10</sub> (and 95% confidence intervals) for the three Wasatch Front metropolitan areas is calculated based on the Poisson regression coefficients for the 5-day lagged moving

average PM<sub>10</sub> using screened data (screen 1) and constructed means for the Salt Lake City and Provo/Orem areas. These estimates equal 1.6% (0.3–2.9), 0.8% (0.3–1.3), and 1.0% (0.2–1.8) for the Ogden, Salt Lake City, and Provo/Orem areas, respectively. These effect estimates are similar to those that have been observed in many other U.S. cities (8,9).

This analysis also evaluated potential mortality associations between barometric pressure and the sensitivity of the estimated pollution effects to controlling for barometric pressure. A recent study explored potential associations between daily changes in blood oxygenation and daily changes in particulate air pollution and barometric pressure (23). Blood oxygenation levels were not significantly associated with particulate air pollution, but they were associated with barometric pressure. Although the changes in barometric pressure and associated changes in oxygen saturation levels were small, the results suggested that barometric pressure should be considered a potentially important weather variable in daily time-series mortality analyses of air pollution. It was speculated

that barometric pressure would be a negative confounder with respect to health effects of air pollution, because it is usually positively associated with particulate air pollution. Excluding it from the analyses would result in underestimating the adverse effects of air pollution. In this analysis, barometric pressure was negatively associated with total and cardiovascular mortality, and excluding it from the analysis resulted in slightly lower particulate pollution effect estimates.

The fact that a mortality association with barometric pressure can be observed is intriguing. At a constant elevation on the valley floors of the Wasatch Front, changes in weather conditions result in some natural variability in barometric pressure, yet this variation is small. Based on the regression results from the Salt Lake City area, a 2-SD (standard deviation) decline in barometric pressure (approximately 0.32 inches or 8 mm Hg) is associated with an average increase in daily mortality of approximately 3.5%. In comparison and also based on the regression results from the Salt Lake City area, a 2-SD increase in PM<sub>10</sub> (48.6  $\mu\text{g}/\text{m}^3$ ) is associated with an average increase in daily mortality of approximately 3.8%. These associations are small but observable using Poisson regression to analyze daily mortality counts of more than 10 years of data from a population of approximately 1 million people. The fact that this methodology is capable of observing such effects is remarkable. The validity and public health significance of these apparent effects remain debatable.

The most fundamental concern about this study is that the associations between PM<sub>10</sub> and mortality are due to confounding. This confounding may occur if a risk factor that is also correlated with day-to-day changes in PM<sub>10</sub> is not adequately controlled for in the analysis, resulting in spurious correlations. Risk factors such as cigarette smoking or socioeconomic variables may contribute to the baseline or underlying cardiopulmonary disease rates in the population, but because they do not change day-to-day in correlation with PM<sub>10</sub> pollution, they are not potential confounders. Because there are day-to-day correlations between pollution, season, and weather variables, confounding by weather variables is a concern. However, positive statistically significant associations between daily mortality and PM<sub>10</sub> were observed even after controlling for seasonality using highly flexible nonparametric smooths of time. Controlling for barometric pressure, daily low temperature, and dew point actually resulted in somewhat larger PM<sub>10</sub> effect estimates.

The most likely confounder for the PM<sub>10</sub>–mortality association observed in this study would be another pollutant or

combination of pollutants that were in fact responsible for the mortality and that were highly positively correlated with  $PM_{10}$ . Along the Wasatch Front,  $PM_{10}$  is not positively correlated with  $O_3$ . During episodes when particulate pollution levels are the highest,  $O_3$  levels are relatively low because the conditions necessary for substantial  $O_3$  formation do not exist.  $PM_{10}$  levels are correlated with general stagnant air conditions when concentrations of  $SO_x$ ,  $NO_x$ , and CO may also be elevated.  $PM_{10}$  may be serving as a measure of community air pollution of primarily combustion-related pollutants including primary and secondary combustion-source particles that are collectively responsible for the apparent mortality effects. It is possible that the true culprit pollutant is a constituent of  $PM_{10}$  such as combustion particles alone, sulfate particles, or fine or ultra-fine particles. The results suggest that primary and secondary fine combustion-source particles common during stagnant air mass conditions pose a greater health risk than windblown crustal-derived particles.

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## CONFERENCE ANNOUNCEMENT

### Women's Health & the Environment: The Next Century Advances in Uterine Leiomyoma Research October 7 - 8, 1999 National Institute of Environmental Health Sciences Research Triangle Park, North Carolina

Uterine leiomyoma (fibroids) is the most common gynecologic neoplasm in women of reproductive age and, as the leading cause of hysterectomy, these tumors have a profound negative impact on women's health. The goal of this conference is to advance our understanding of the pathogenesis and treatment of uterine leiomyoma, with emphasis on the role that environmental factors play in tumor development. Conference participants will be drawn from the fields of basic science, epidemiology and therapeutics.

**For Registration and Additional Information Contact:**  
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